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Matheson et al. Supernova 1993J

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Detailed Analysis of Early to Late-Time Spectra of Supernova 1993J

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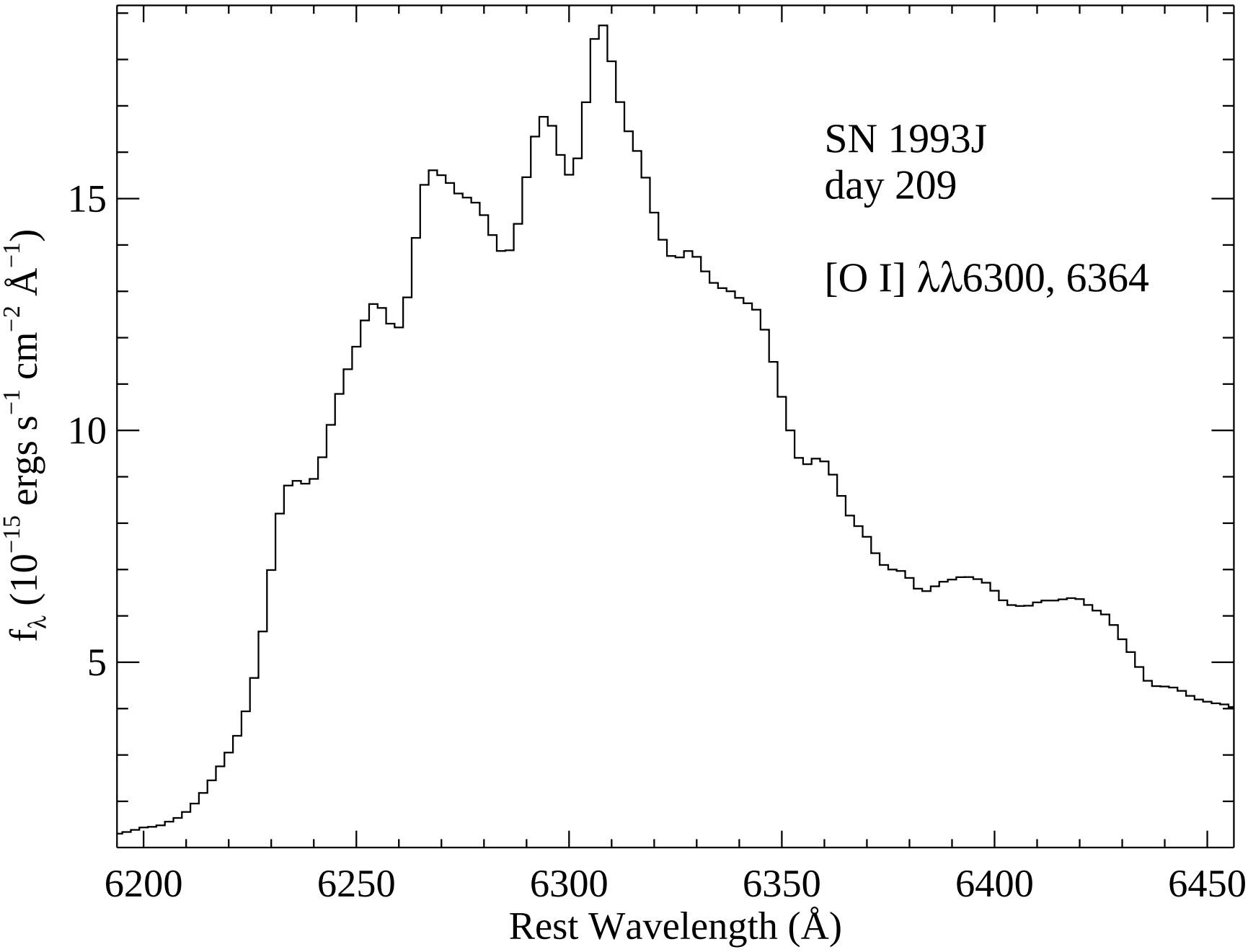
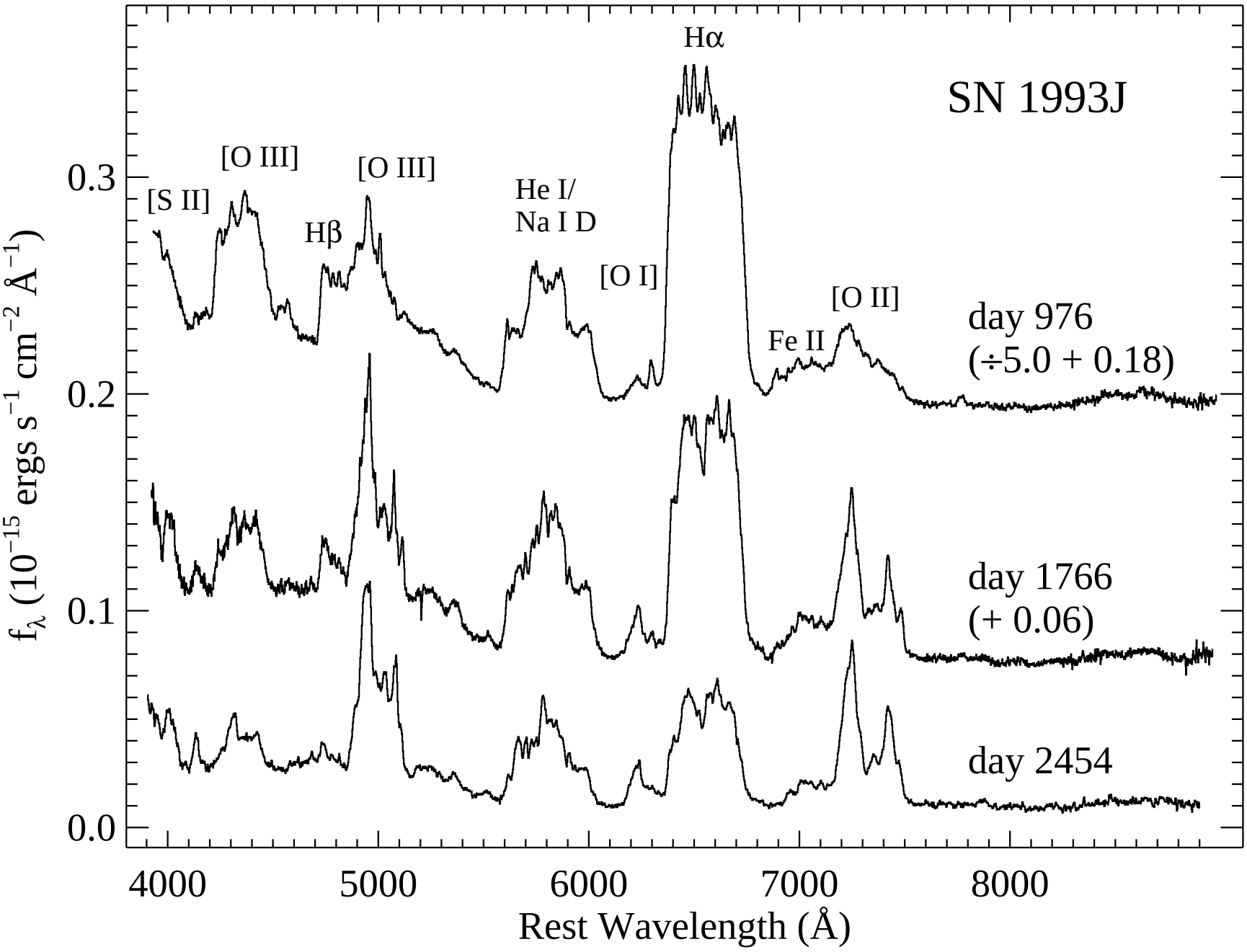
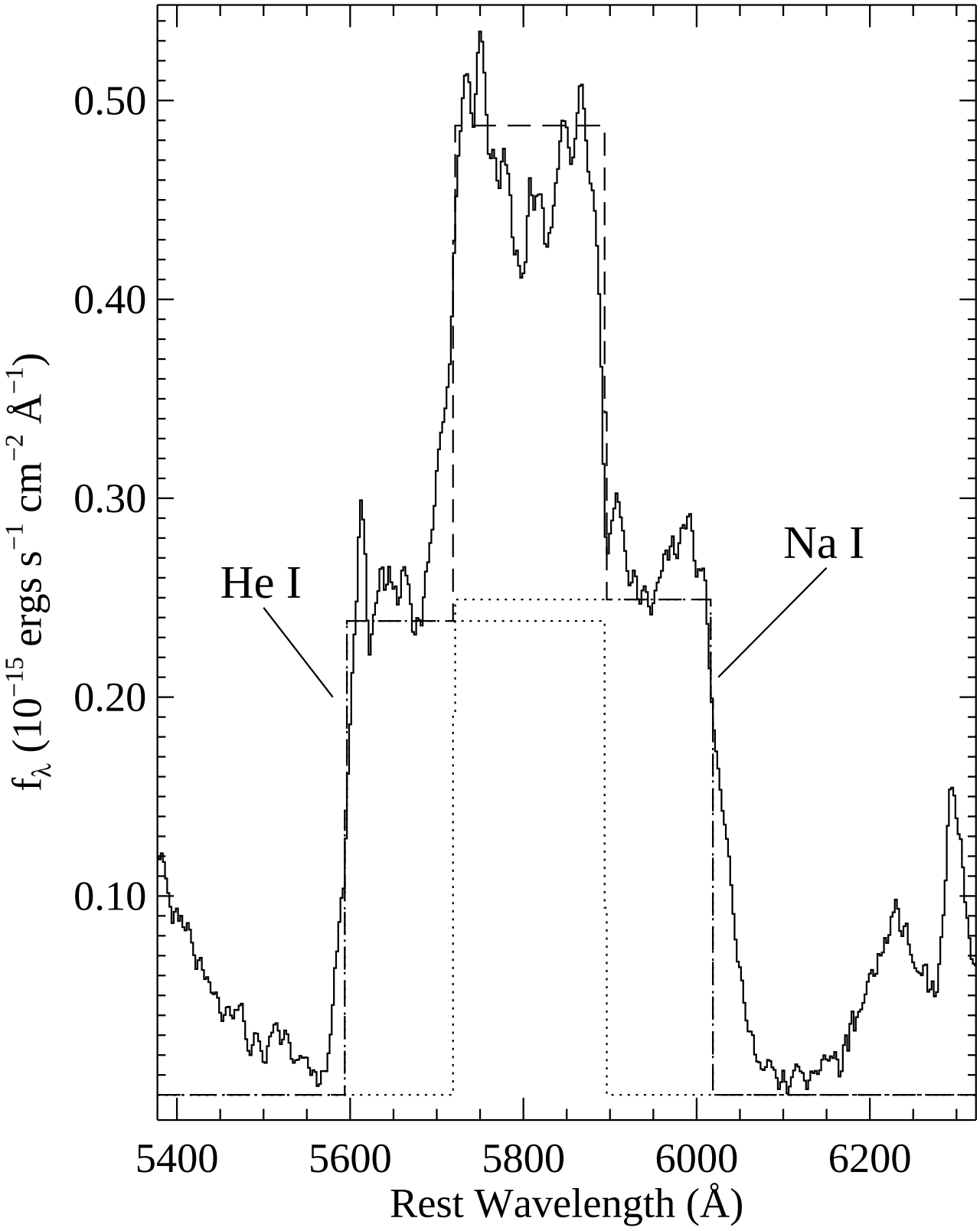
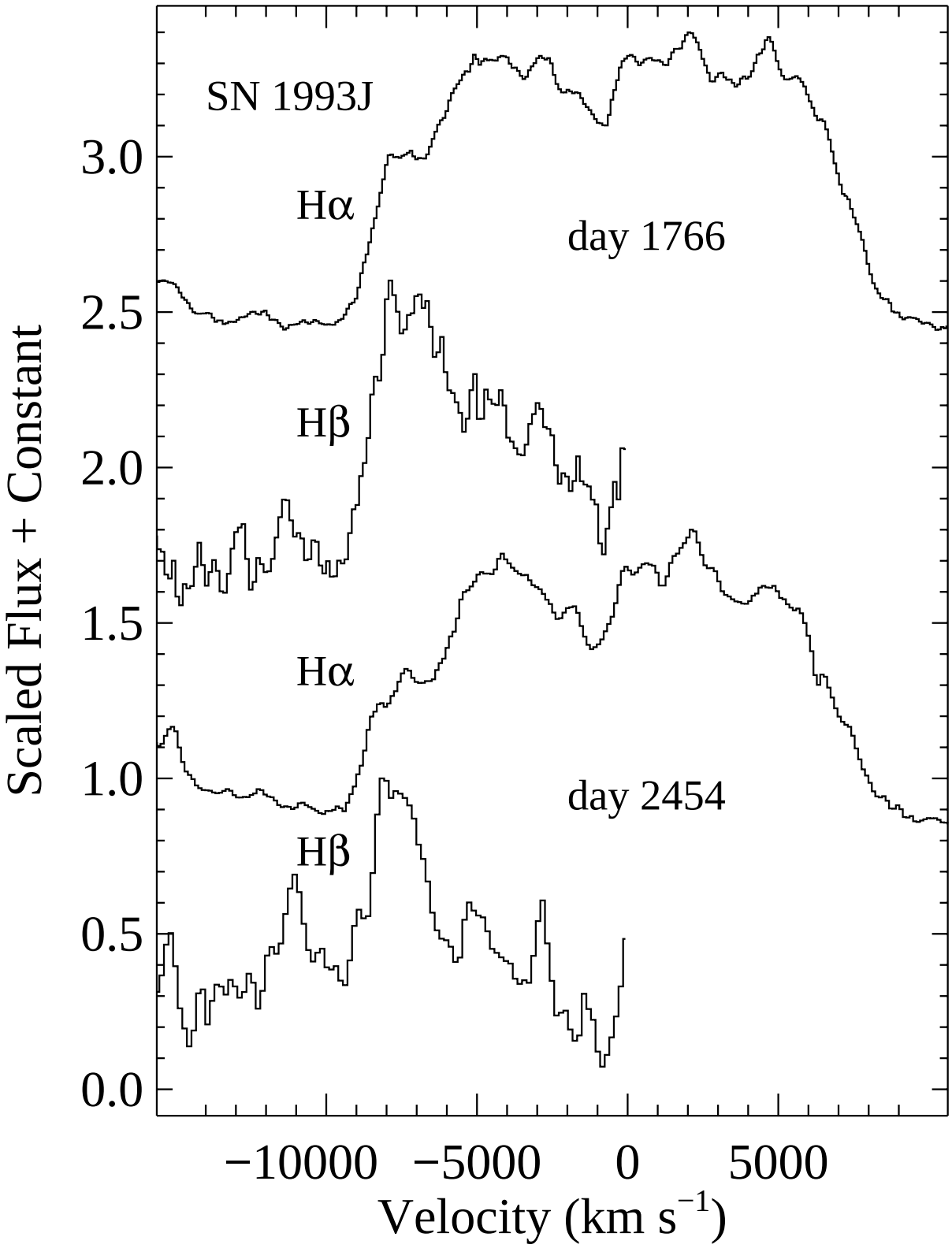
abstract

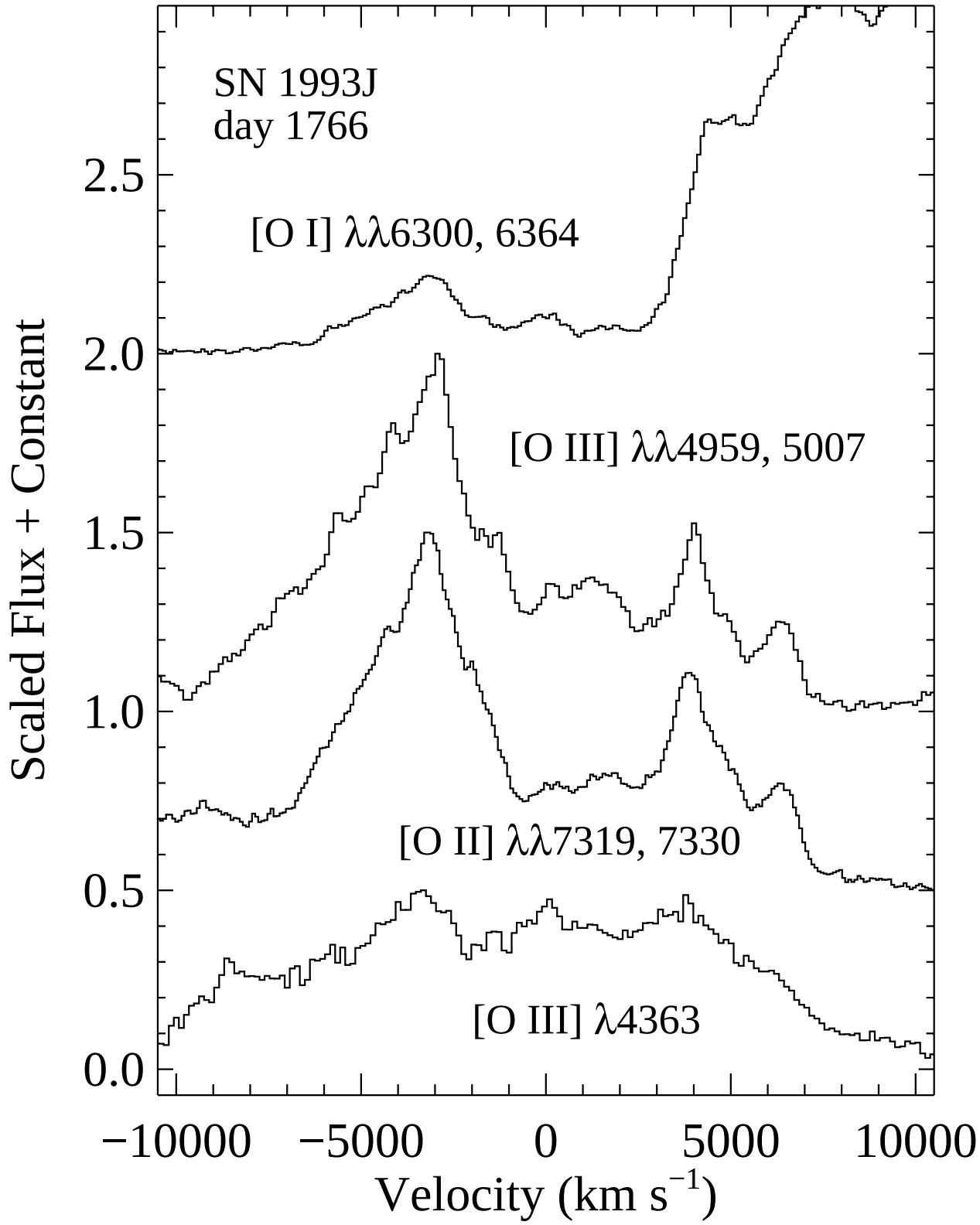
We present a detailed study of line structure in early to late-time spectra of Supernova (SN) 1993J. Spectra during the nebular phase, but within the first two years after explosion, exhibit small-scale structure in the emission lines of some species, notably oxygen and magnesium, showing that the ejecta of SN 1993J are clumpy. On the other hand, a lack of structure in emission lines of calcium implies that the source of calcium emission is uniformly distributed throughout the ejecta. These results are interpreted as evidence that oxygen emission originates in clumpy, newly synthesized material, while calcium emission arises from material pre-existing in the atmosphere of the progenitor. Spectra spanning the range $433 - 2454$ days after the explosion show box-like profiles for the emission lines, clearly indicating circumstellar interaction in a roughly spherical shell. This is interpreted within the Chevalier & Fransson (1994) model for SNe interacting with mass lost during prior stellar winds. At very late times, the emission lines have a two-horned profile, implying the formation of a somewhat flattened or disk-like structure that is a significant source of emission. The very high signal-to-noise ratio spectra are used to demonstrate the potential significance of misinterpretation of telluric absorption lines in the spectra of bright SNe.

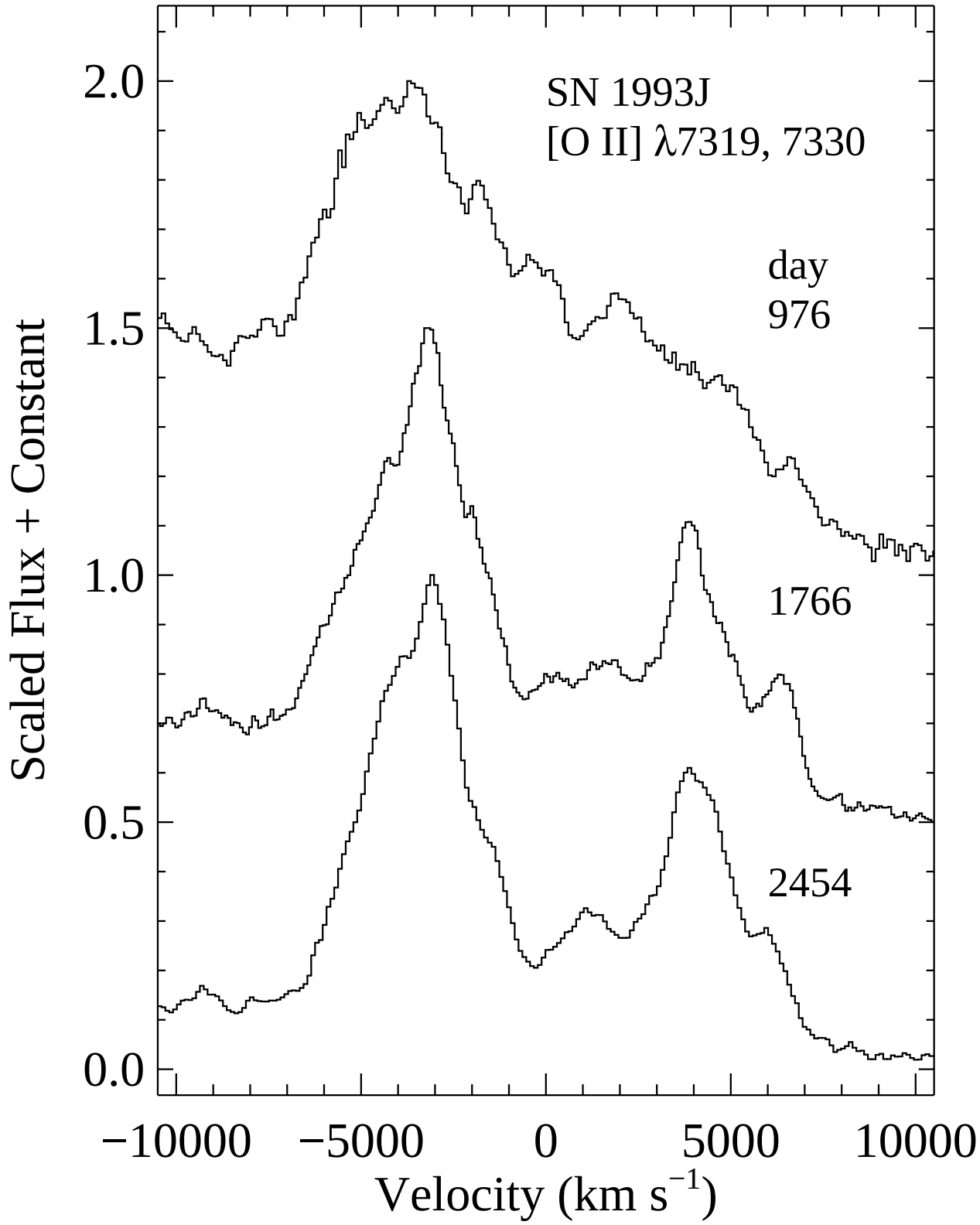

SN 1993J
day 209
[O I] λλ6300, 6364
15
10
5
6200
6250
6300
6350
6400
6450
Rest Wavelength (Å)
f_λ (10^−15 ergs s^−1 cm^−2 Å^−1)

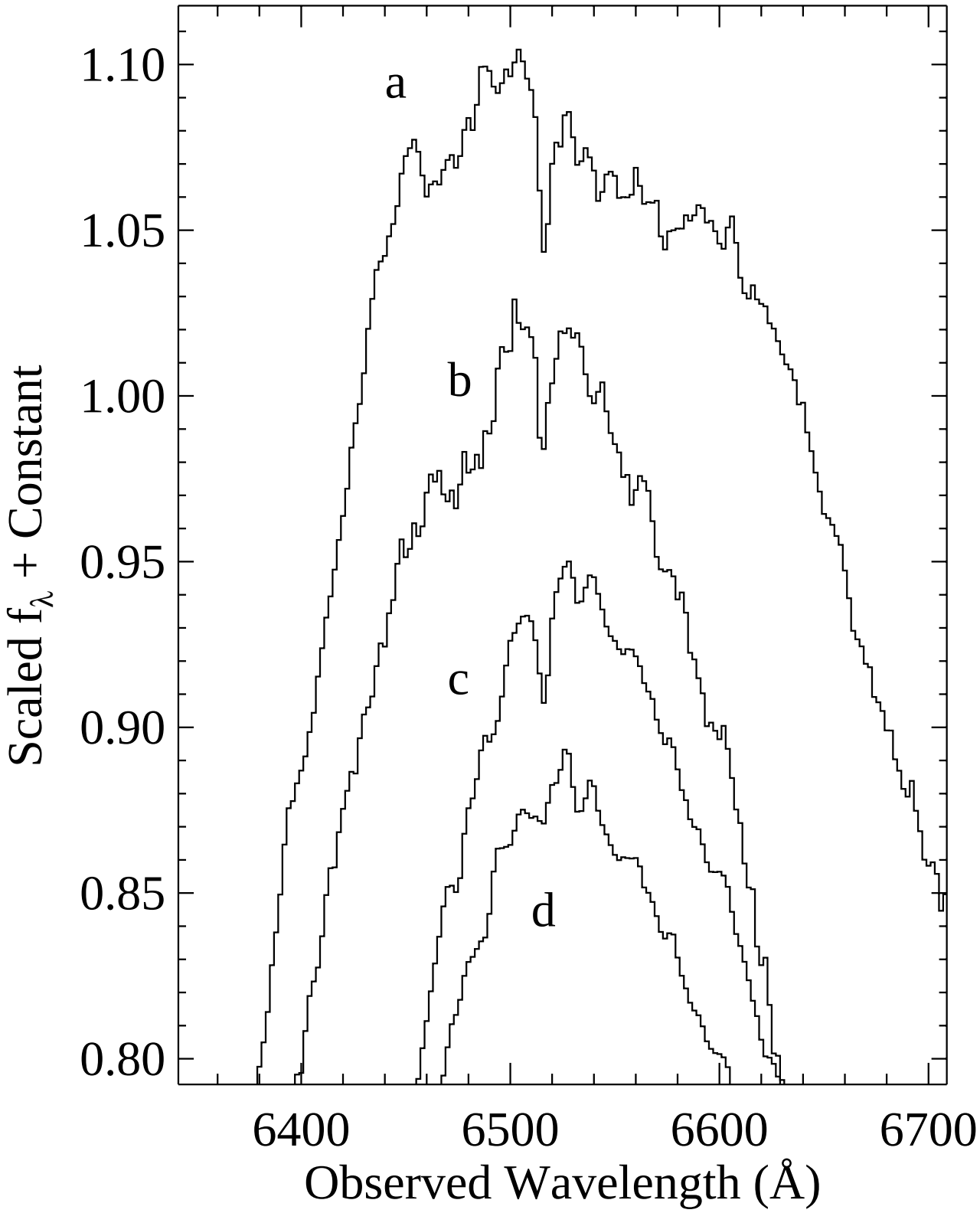

SN 1993J
Hα
[S II]
[O III]
Hβ
[O III]
He I/
Na I D
[O I]
[O II]
Fe II
day 976
(÷5.0 + 0.18)
day 1766
(+ 0.06)
day 2454
0.0
0.1
0.2
0.3
4000
5000
6000
7000
8000
Rest Wavelength (Å)
f_λ (10^−15 ergs s^−1 cm^−2 Å^−1)

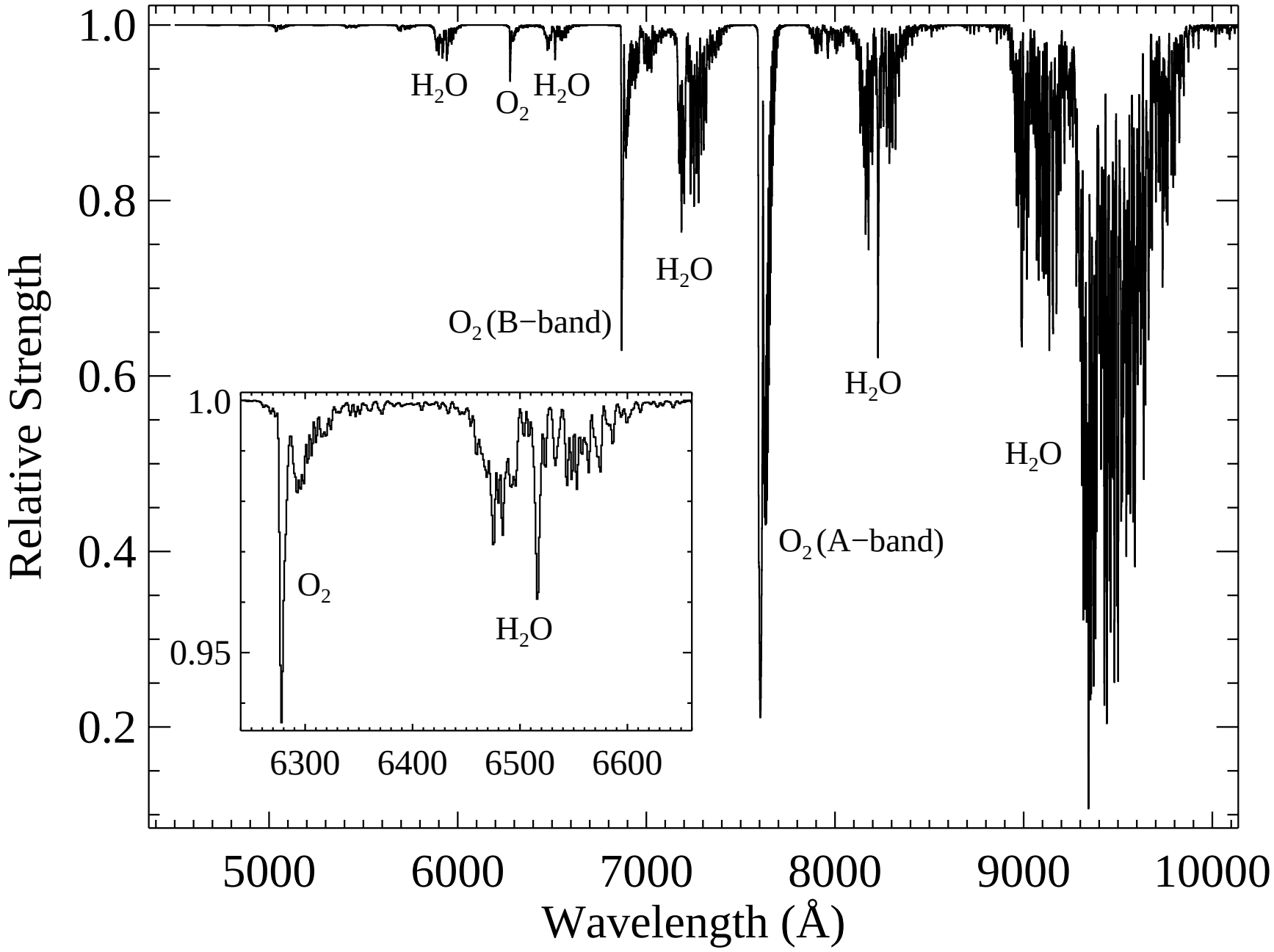

0.50
0.40
0.30
0.20
0.10
f_λ (10^{-15} ergs s^{-1} cm^{-2} Å^{-1})
He I
Na I
5400
5600
5800
6000
6200
Rest Wavelength (Å)

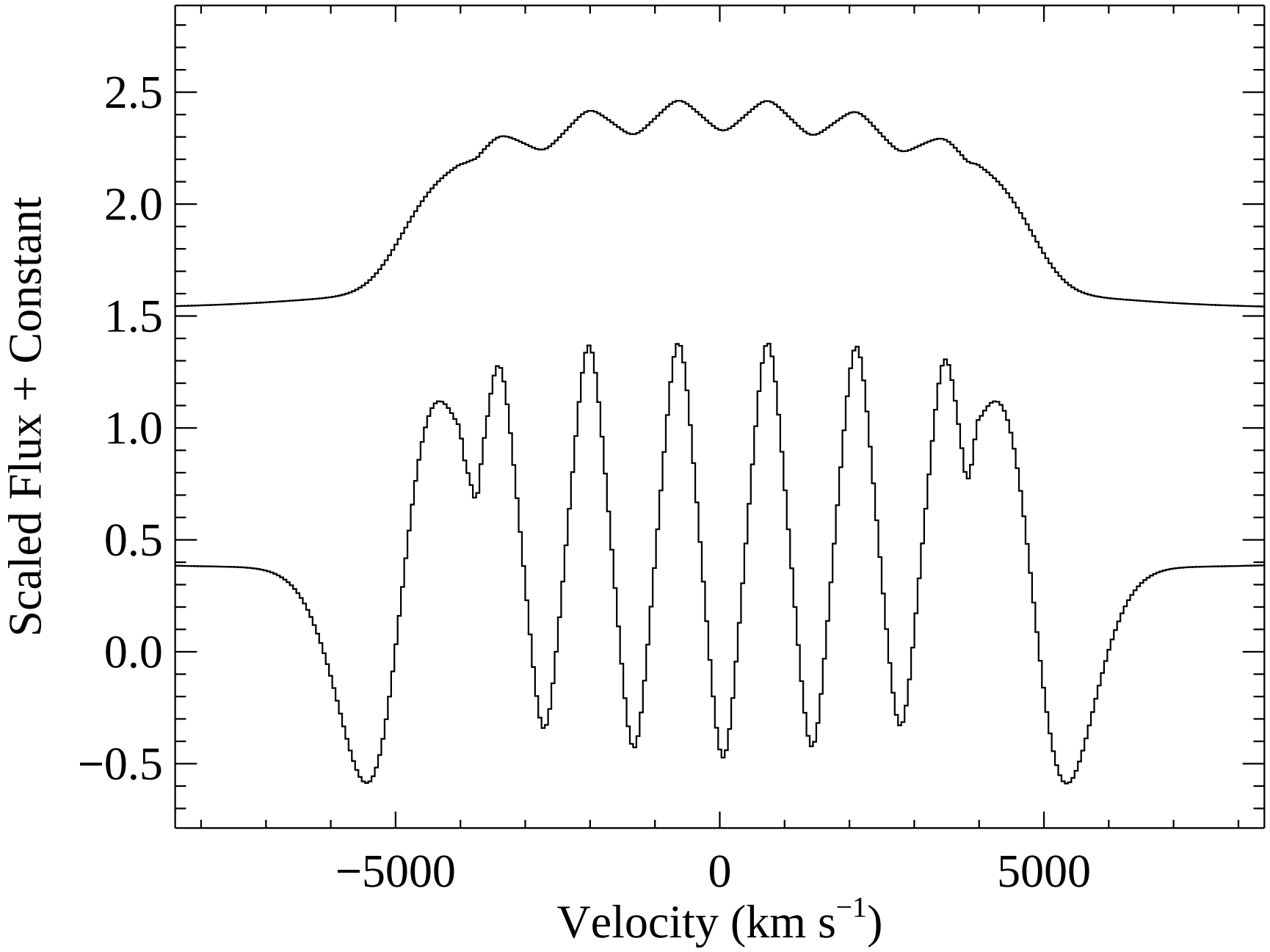

SN 1993J
Hα
day 1766
Hβ
Hα
day 2454
Hβ
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Scaled Flux + Constant
−10000
−5000
0
5000
Velocity (km s^{-1})

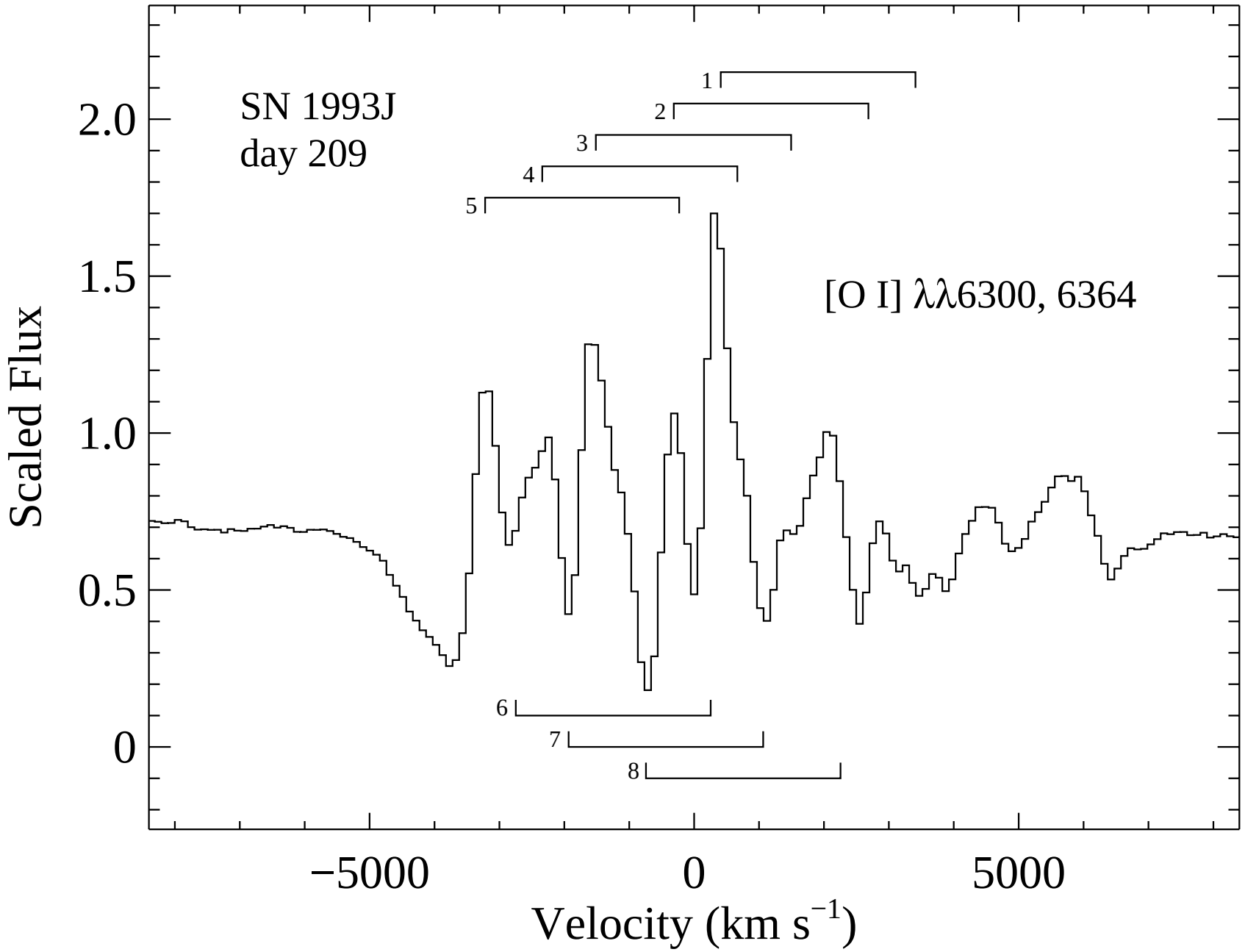

SN 1993J
day 1766
[O I] λλ6300, 6364
[O III] λλ4959, 5007
[O II] λλ7319, 7330
[O III] λ4363
Scaled Flux + Constant
0.0
0.5
1.0
1.5
2.0
2.5
−10000
−5000
0
5000
10000
Velocity (km s^{-1})

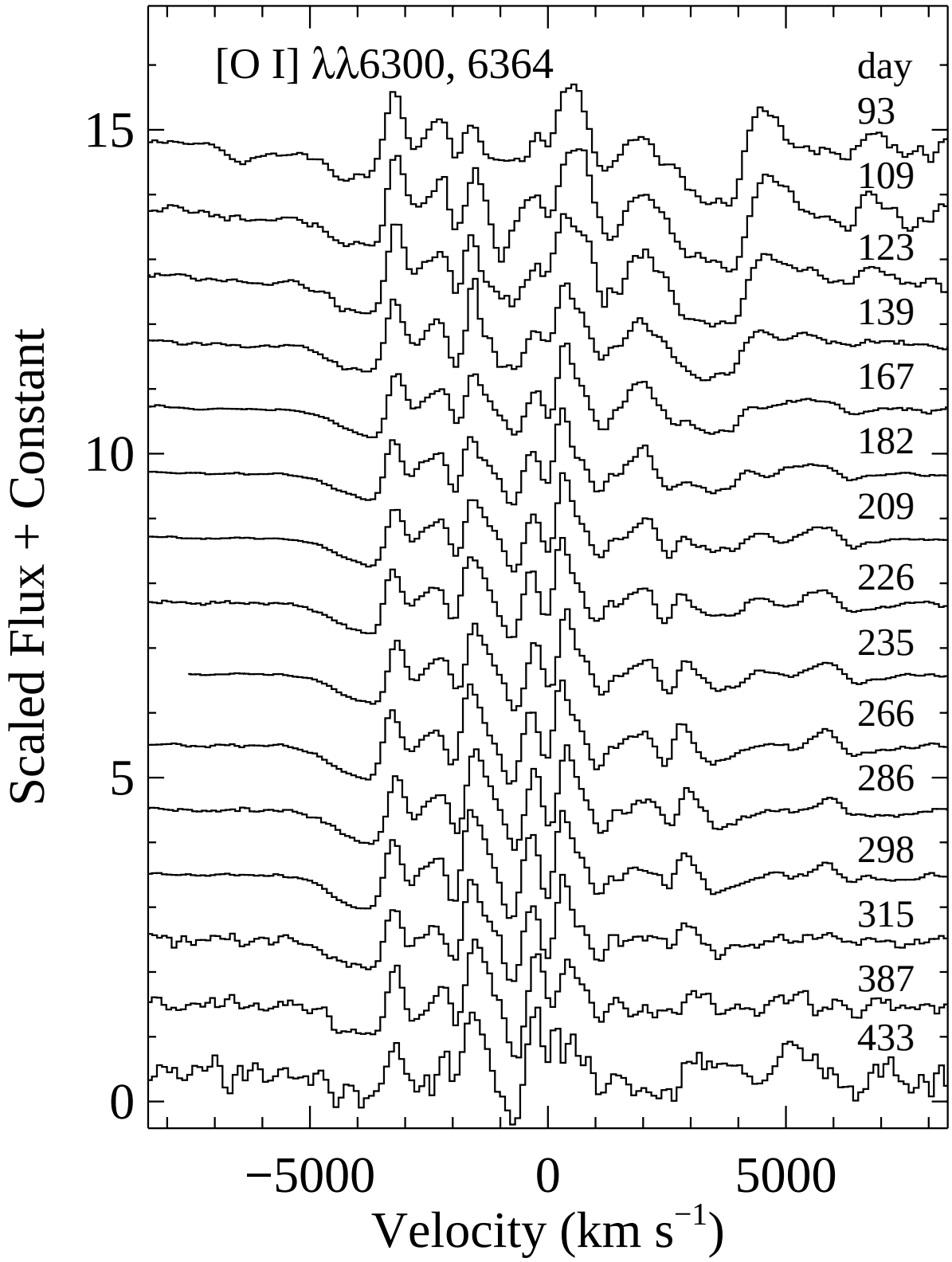

SN 1993J
[O II] λ7319, 7330
day
976
1766
2454
2.0
1.5
1.0
0.5
0.0
Scaled Flux + Constant
−10000
−5000
0
5000
10000
Velocity (km s^{-1})

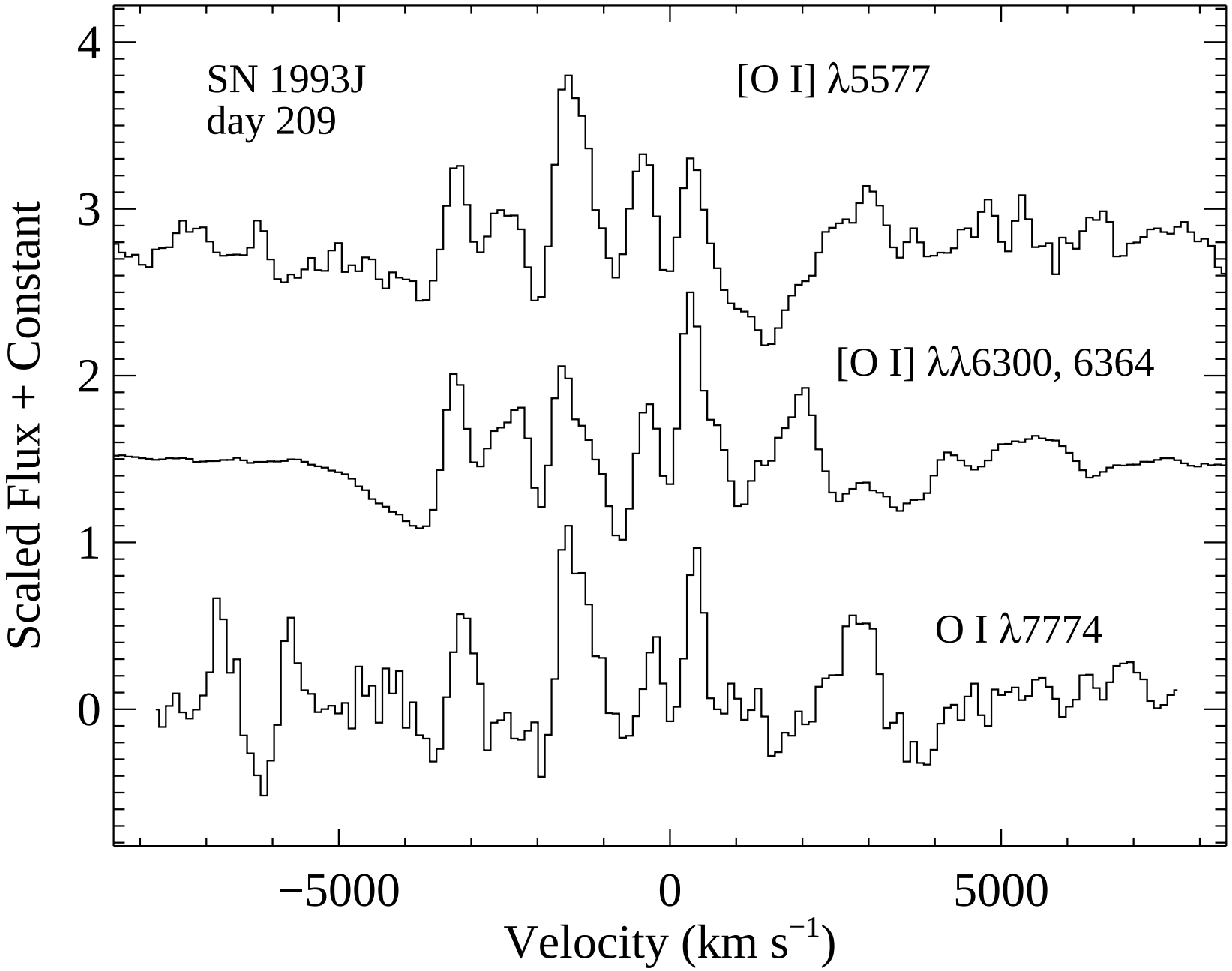

1.10
1.05
1.00
0.95
0.90
0.85
0.80
Scaled f_λ + Constant
a
b
c
d
6400
6500
6600
6700
Observed Wavelength (Å)

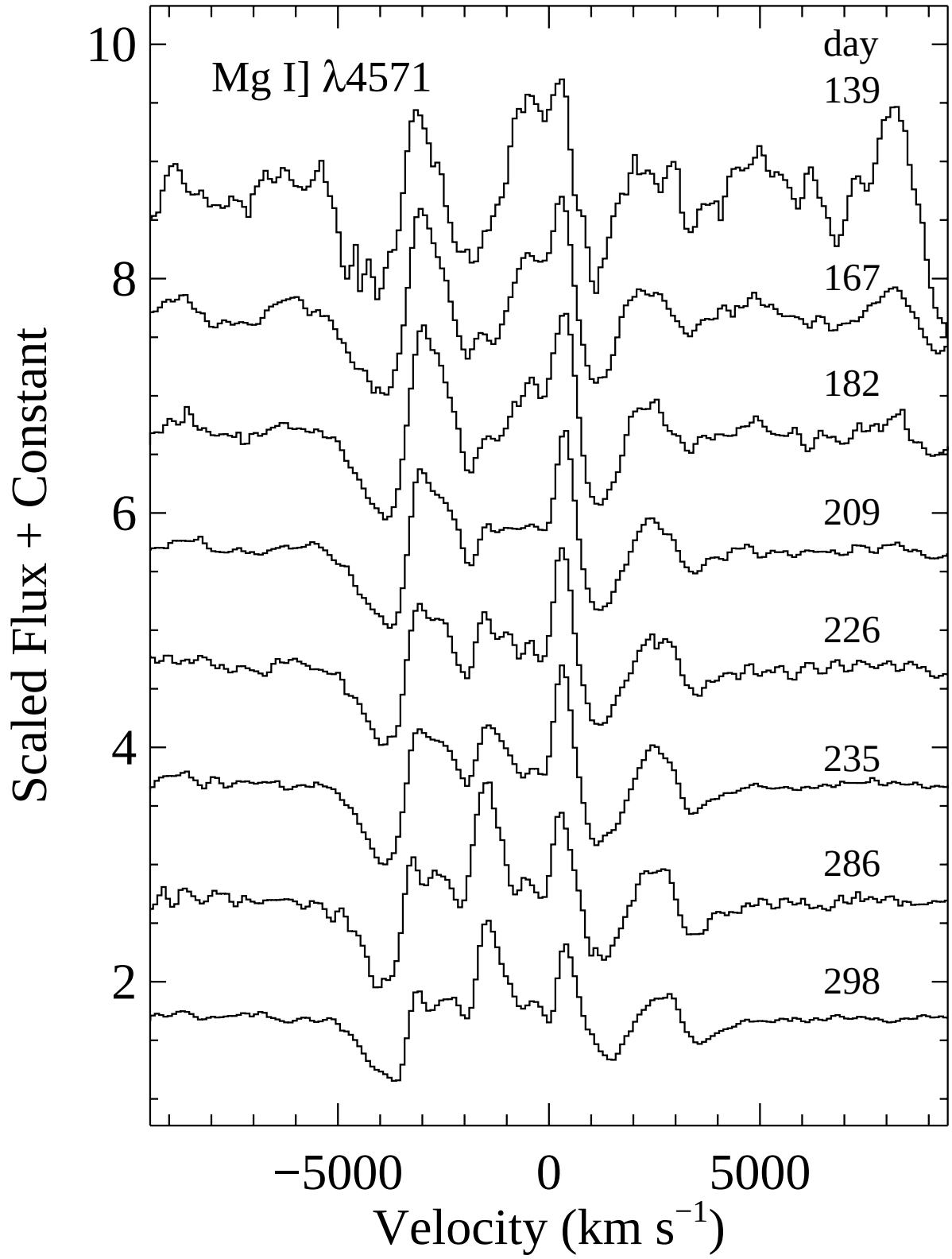

1.0
0.8
0.6
0.4
0.2
Relative Strength
H2O
O2
H2O
H2O
O2 (B−band)
H2O
O2 (A−band)
H2O
H2O
1.0
0.95
O2
H2O
6300
6400
6500
6600
5000
6000
7000
8000
9000
10000
Wavelength (Å)

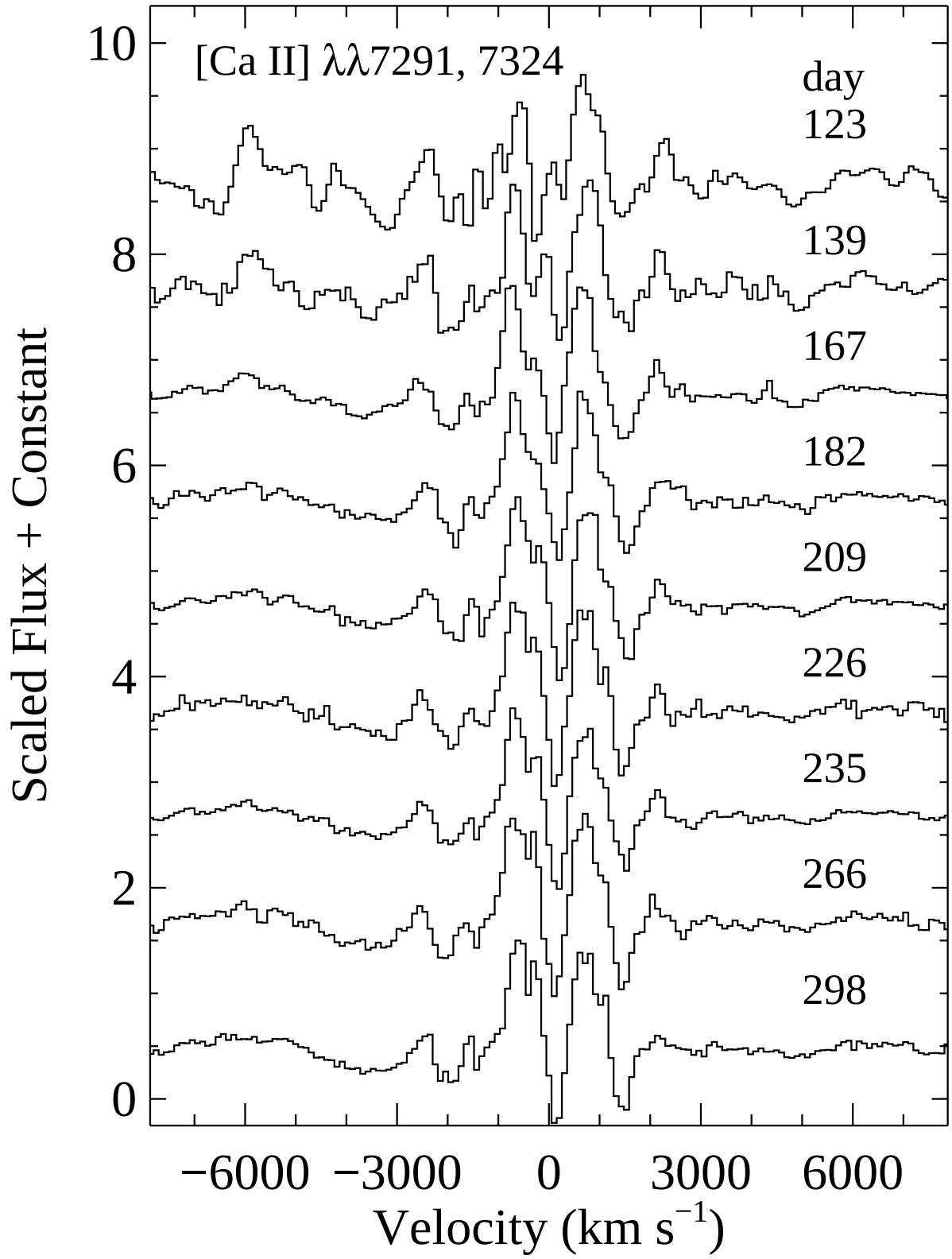

2.5
2.0
1.5
1.0
0.5
0.0
−0.5
Scaled Flux + Constant
−5000
0
5000
Velocity (km s^{-1})

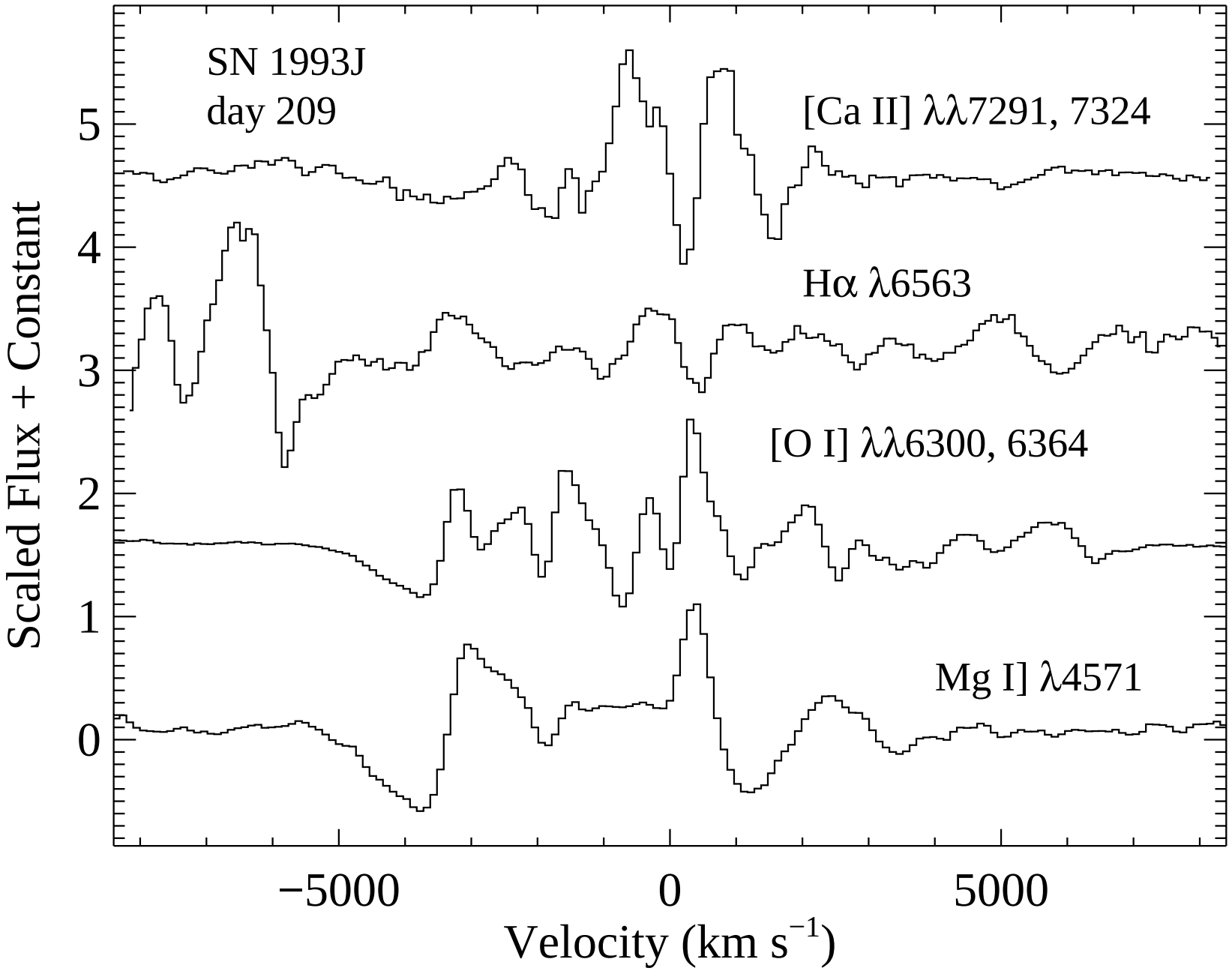

SN 1993J
day 209
[O I] λλ6300, 6364
1
2
3
4
5
6
7
8
2.0
1.5
1.0
0.5
0
Scaled Flux
−5000
0
5000
Velocity (km s^{-1})

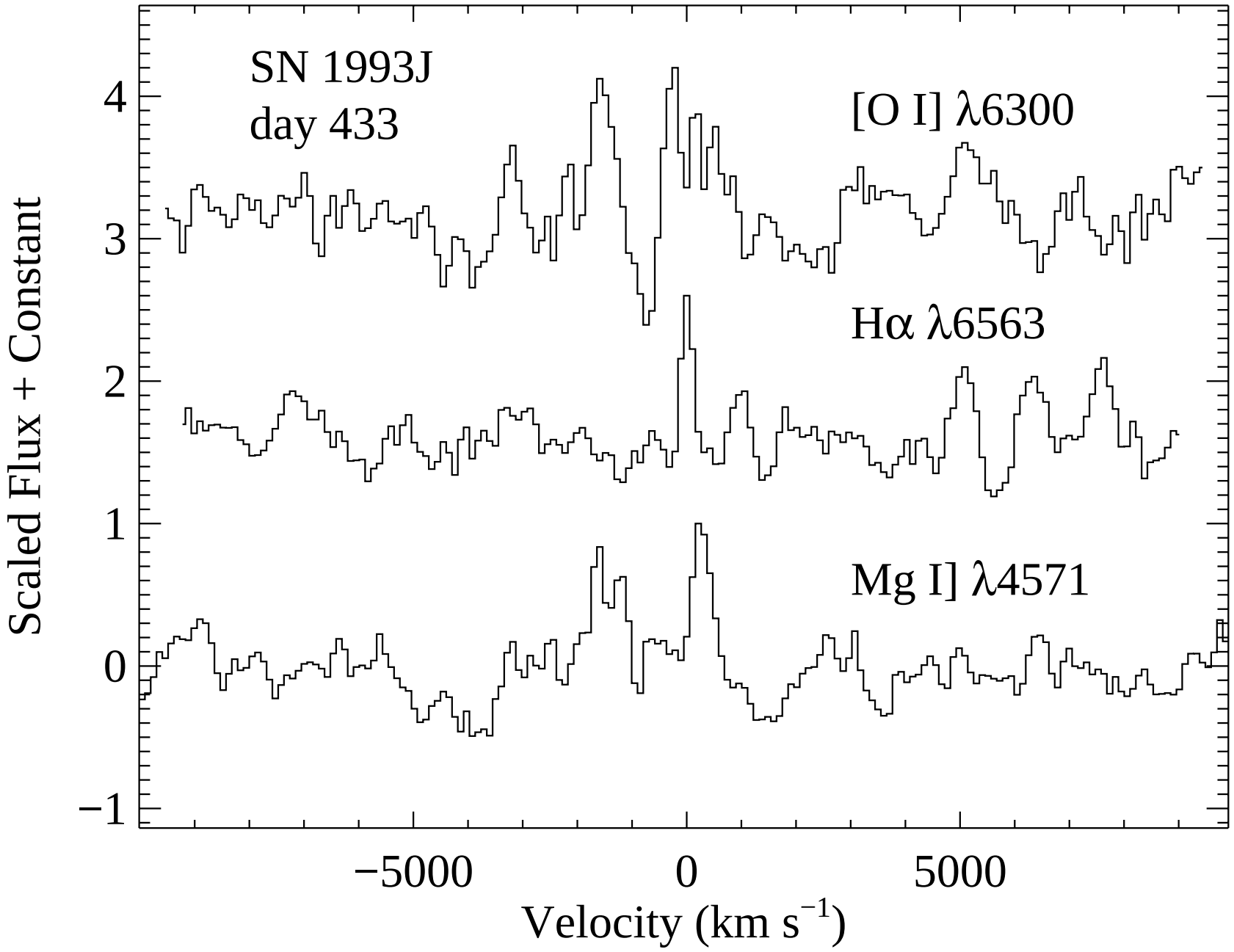

[O I] λλ6300, 6364
day
93
109
123
139
167
182
209
226
235
266
286
298
315
387
433
15
10
5
0
Scaled Flux + Constant
−5000
0
5000
Velocity (km s^{-1})


SN 1993J
day 209
[O I] λ5577
[O I] λλ6300, 6364
O I λ7774
Scaled Flux + Constant
Velocity (km s^{-1})
4
3
2
1
0
−5000
0
5000


Mg I] λ4571
day
139
167
182
209
226
235
286
298
10
8
6
4
2
Scaled Flux + Constant
−5000
0
5000
Velocity (km s^{-1})


[Ca II] λλ7291, 7324
day
123
139
167
182
209
226
235
266
298
Scaled Flux + Constant
Velocity (km s^{-1})
10
8
6
4
2
0
−6000
−3000
0
3000
6000


SN 1993J
day 209
[Ca II] λλ7291, 7324
Hα λ6563
[O I] λλ6300, 6364
Mg I] λ4571
Scaled Flux + Constant
0
1
2
3
4
5
−5000
0
5000
Velocity (km s^{-1})


SN 1993J
day 433
[O I] λ6300
Hα λ6563
Mg I] λ4571
Scaled Flux + Constant
Velocity (km s^{-1})
4
3
2
1
0
−1
−5000
0
5000